NASA microgravity research highlights

Two μg Missions Reviewed: "Real Science — It's Like Real Life"

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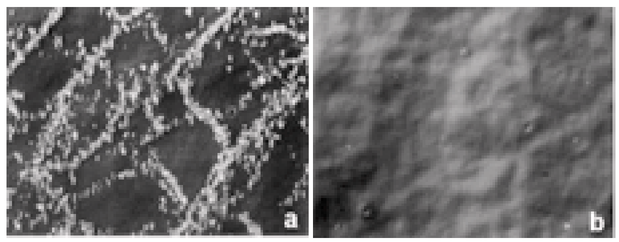
After every microgravity science spaceflight mission, there is a formal review of the scientific data and results one year following the launch of the mission, or in NASA shorthand, "L+1." The year gives principal investigators (PIs) and their research teams time to analyze and assess their data before presenting conclusions to their fellow mission investigators; their peers in the scientific research community; and their sponsors, the public. Because the Microgravity Research Division (MRD) supported two microgravity missions that occurred only months apart, it was appropriate to combine the two L+1 reviews. On February 10-11, 1997, investigators from NASA, academia, and industry gathered at the National Academy of Sciences in Washington, D.C., to report the results of the second United States Microgravity Laboratory mission (USML-2), which flew in October 1995, and the third United States Microgravity Payload mission (USMP-3), which flew in March 1996.

The meeting was launched by comments from MRD Director Robert C. Rhome, who said the review was held "to partially fulfill our responsibility to report scientific results to the American public and to recognize the considerable efforts of the teams of scientists, engineers, technicians, and managers who make the use of an orbiting research laboratory possible." Rhome recounted the history of the two series and concluded by praising the results of the series' early missions (USML-1, USMP-1, and USMP-2), which showed the microgravity environment to be a unique tool in pursuing research questions in such diverse areas as biotechnology, combustion science, fluid physics, fundamental physics, and materials science.

"Totally Unanticipated"

Indeed, the presentations given at the USML-2 and USMP-3 L+1 Review seemed to be as much about questions as about answers. Many of the experiments of these two missions were follow-up investigations to experiments conducted earlier in the series. PIs in the area of materials science, in particular, spent time outlining unexpected results from previous missions and describing how they redesigned experiments to try to resolve them.

Investigators David Larson (State University of New York, Stony Brook), David Matthiesen (Case Western Reserve University, CWRU), and Heribert Wiedemeier (Rensselaer Polytechnic Institute, RPI) reported that, in general, the samples of electronic materials that they solidified on USML-1 were more uniform than samples grown on the ground. However, they also discovered unusual effects in the space-grown materials. Larson observed "a totally unanticipated lack of twinning" in a part of the sample of zinc-alloyed cadmium telluride that he grew on USML-1. Twinning, Larson explained, "is a crystal defect pervasive in industrial processing of this family of materials." Larson's team decided that the part of the sample that showed no twinning seemed to have little contact with the ampoule wall. They adjusted the experiment on USML-2 to eliminate contact with the ampoule throughout the sample and were able to grow a sample that had no evidence of twinning. "An imperfect material on the ground suddenly looked like a perfect material in microgravity," reported Larson.



Samples of zinc-alloyed cadmium mercury grown on Earth (photo a) and in space (photo b) are shown at the same magnification. The space-grown crystal has a more uniform microstructure.

Mysterious voids, or bubbles, appeared in the center of Matthiesen's USML-1 samples of selenium-doped gallium arsenide, which is a material that may one day replace silicon in computer applications. Although bubbles rise to the surface of a material when solidified on the ground, they do not in microgravity, and finding a way to eliminate these voids was a new challenge for Matthiesen and his team. After much thought and more modeling of the solidification process, Matthiesen refined the experiment for USML-2 to eliminate the voids. Another challenge Matthiesen met on USML-2 was improving the experiment's ability to mark, or record, the liquid/solid interface shape in the sample during solidification. Matthiesen and the experiment engineering team accomplished this by redesigning the experiment to send an electric impulse (rather than a mechanical one) through the sample to mark the shape. Being able to "see" the interface shape, which is key to understanding the solidification process, allowed Matthiesen to pinpoint where the experiment matched predictions made by the computer model and where it did not. This information will aid the general work to develop furnaces for use on the ground and on the International Space Station, as well as the specific work to control the growth of selenium-doped gallium arsenide crystals in order to further improve their electronic properties.

On USML-1, Wiedemeier used the vapor transport method to form a layer of mercury cadmium telluride, a semiconductor material, on a substrate, or base layer of another material. The purpose of the substrate is to help order the crystalline structure of the material formed on top of it (the epitaxial layer). Wiedemeier found that the mercury cadmium telluride formed during USML-1 was smoother (with less defects) than samples of the material formed using the same method on Earth. Wiedemeier wanted to examine the interface of the substrate and epitaxial layer more closely, since on Earth, the interface is where defects or roughness occur and then translate throughout the epitaxial layer. To do this kind of close examination of the interface, Wiedemeier reduced the thickness of the epitaxial layer from the 40-50 microns of the USML-1 samples to 10 microns for the first USML-2 sample and to 4 microns for the second sample. Getting the mercury cadmium telluride to deposit evenly at such a thickness was a feat in itself, and the resulting samples were not only thinner but smoother than samples grown on Earth. Using data from these samples, Wiedemeier continues to look for clues to understanding defect formation and translation in epitaxial growth.

USMP-3 materials scientists experienced mixed luck in solving some of the mysteries of previous and recent results. Jean-Paul Garandet, co-investigator for the USMP-3 experiment that used the French solidification furnace MEPHISTO, reported progress in designing a model that can predict the effect of shuttle thruster firings on solidification experiments. The French team, led by PI Jean-Jacques Favier (representing the French Atomic Commission and the French National Center for Space Studies, CNES), decided to construct such a model after observing the sensitivity of their USMP-1 experiment to a thruster burn. Another USMP-3 researcher, Archie Fripp (Langley Research Center), reported that, although he expected to see some differences among the samples of the electronic material lead tin telluride, which he solidified in a variety of shuttle attitudes on USMP-3, he did not expect the pores that were uniformly distributed in the samples. Fripp and his team believe that surface tension might have caused the pores, as the influence of surface tension on the melted sample in microgravity was greater than Fripp had anticipated. He will be using the reflight of the experiment on USMP-4 in October 1997 to explore ways to compensate for the effects of surface tension and eliminate the pores. Fripp said that he and his team will have to "keep figuring" to solve this mystery.

"A Continuing Adventure"

That "figuring" process can be a long and winding path to understanding, as Matthew Koss (RPI) revealed in his presentation "Convection Process in Microgravity: Why We Were Wrong." Koss, co-investigator for the Isothermal Dendritic Growth Experiment (IDGE), and PI Martin Glicksman (RPI) had used the USMP-3 reflight of the IDGE to focus on an unusual result in their USMP-2 samples. The IDGE tests theories of dendritic crystal growth, which have been impossible to confirm on the ground because they call for a purely diffusive heat transport environment. In space, however, a part of the range of conditions selected for the experiment showed what appeared to be unexpected convection. During the L+1 meeting, Koss reviewed the team's pursuit of explanations for the apparent convection. These included the possibility that some convection does occur even in microgravity and the possibility that the container walls were causing the effect. The RPI team tentatively concluded that convection was the culprit, but resolving the issue definitively was one objective of the USMP-3 reflight of the experiment. Results of the USMP-3 run of the IDGE showed that the team's preliminary conclusions were wrong; the container walls were the cause.

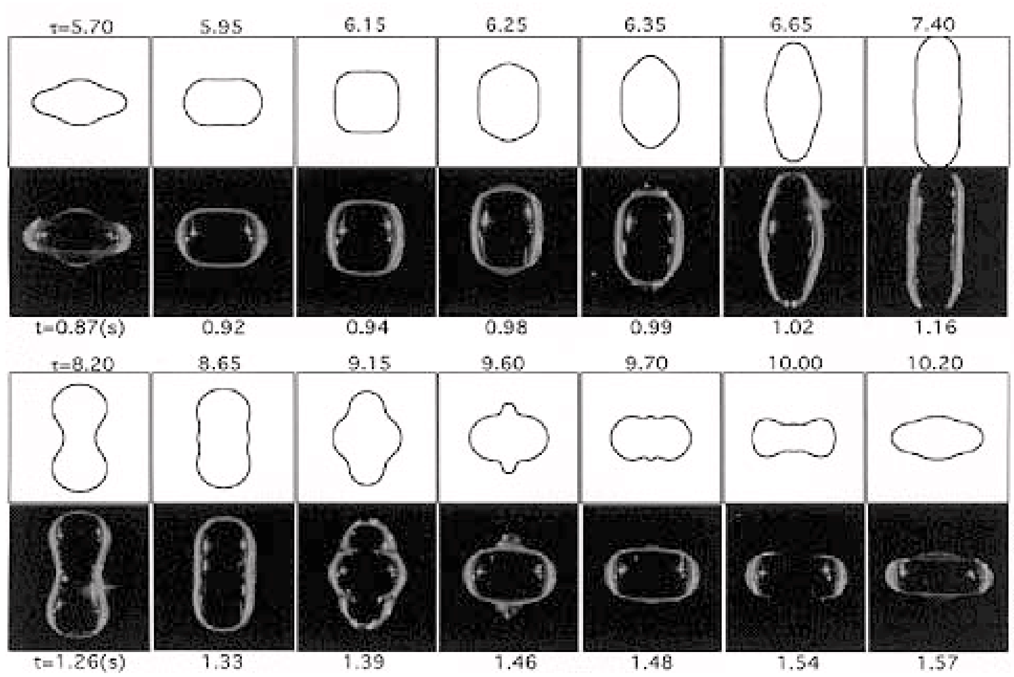
Koss' presentation struck a chord with fellow investigators in the audience because it was an experience to which all of them could relate. Audience members praised the presentation for being an "honest" and "unglossed" account of scientific research, which is rarely a case of postulating a question, collecting unambiguous data, and reaching a definitive conclusion on the first attempt. Now that the RPI team has resolved the "convection issue," it can move on to the main objective of the experiment, which is to use the experiment data to map the shape of a dendrite tip as it solidifies. This mapping is currently under way at RPI and will ultimately contribute to understanding and controlling the complex process of dendrite formation.

PI Robert Gammon's experiment was a perfect example of the enduring nature of data and the quest to reconcile it with theory. Gammon (University of Maryland, College Park) described this quest as "a continuing adventure." His experiment, Critical Fluid Light Scattering (also referred to as "Zeno"), investigates an unusual condition in nature called the liquid/vapor critical point. This point was described by Gammon as "a special place in nature that is difficult to get to. The only place where it occurs naturally is inside stars." Conducting the experiment requires very small and careful changes in the temperature of a sample of xenon to bring it close to the critical point, the highest temperature at which liquid and vapor phases of a substance can coexist. Xenon is chosen as the sample because it has a convenient critical point temperature — just below room temperature — although it must also be under exceedingly high pressure. Gammon reported that on USMP-2, they were able to bring the sample closer to this point than on USMP-3, but they did so with less control. On USMP-3, the team was better able to control the parameters of the experiment, which gave them clues for reinterpreting the data from USMP-2. Said Gammon, "The first flight was more valuable in terms of data, but we wouldn't have been able to understand that data without resolving these issues in the second flight of the experiment."

"All the Difference"

Fluid physicists experimenting on USML-2 reported the most dramatic increase in the amount of experiment data collected compared to previous shuttle runs of their experiments. For USML-2, engineers were able to increase the number of video downlinks from the shuttle to the Payload Operations Control Center (POCC) at Marshall Space Flight Center in Alabama from one channel on USML-1 to six on USML-2. This increase meant that PIs received more pictures of fluid behavior under the unique conditions of microgravity than ever before.

Dan Ohlsen (University of Colorado, Boulder) reported the Geophysical Fluid Flow Cell (GFFC) benefited tremendously from the high-packed (HI-PAC) digital video images. The GFFC, which Ohlsen calls "a planet in a test tube," simulates the astrophysical flows in stars and planets. These flows are impossible to model accurately in Earth's gravity. Ohlsen, co-investigator for the experiment; John Hart, principal investigator; and the rest of the GFFC team received over 100,000 images of convection patterns occurring in the experiment fluid,



Apfel's excellent match: This series of photos shows a water drop containing a surfactant (Triton-100) as it experiences a complete cycle of superoscillation during USML-2. The time in seconds appears under the photos. The figures above the photos are the oscillation shapes predicted by a numerical model. The time shown with the predictions is nondimensional.

which surrounds a rotating hemisphere. GFFC Co-Investigator Fred Leslie, a payload specialist onboard the shuttle, was able to change parameters of the experiment in response to the ground team's analysis of HI-PAC images received at the POCC. In Ohlsen's opinion, the amount of data received and the ability to collect it in real time made "all the difference in this run of the experiment." During this run, the GFFC simulated the flows of planets and stars that experience rapid rotation and center heating, such as the Sun and Jupiter, which are both gaseous bodies. The team particularly wanted to probe fluid forces that might be causing Jupiter's continually raging storm, the red spot. The cell also simulated the flows of planets that experience slow rotation, like the Earth. The slow rotation simulations produced some fluid behavior in the GFFC that may be comparable to that of Earth's mantle. Data from the experiment will provide better understanding of the basic physics that drive these astrophysical flows.

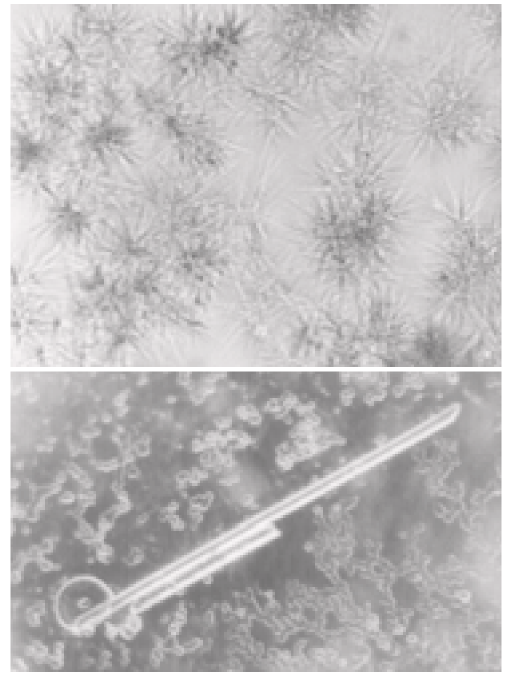
Simon Ostrach (CWRU) also modeled fluid phenomena on USML-2 and, like Ohlsen, reported that the increase in real-time data had a positive impact on his investigation, the Surface Tension Driven Convection Experiment (STDCE). Through HI-PAC, the STDCE team on the ground could see what was happening in the experiment cell better than the astronauts conducting the experiment on the shuttle could. Ostrach felt this improved an experiment that has always been interactive. The team could direct the crew in response to what they were seeing in the experiment, and the scientific yield increased. Ostrach stressed, "It's this serendipity in doing the experiments that makes them really exciting." Also exciting is Ostrach's expectation that the data from this flight of the experiment will confirm his hypothesis regarding the conditions under which thermocapillary flows (flows generated by temperature variations along a liquid's free surface) will transition from a steady, or two-dimensional, state to an oscillatory, or three-dimensional, state. Ostrach says the phenomenon of oscillatory flows is "scientifically fascinating, and its study has numerous implications." One of these implications is that microgravity researchers might be able to avoid such flows in experiments that could be adversely affected by them.

USML-2 PIs Taylor Wang (Vanderbilt University) and Robert Apfel (Yale University) had the most interactive experiments of the mission. Using the Drop Physics Module, Wang investigated the behavior of levitated liquid drops and compound drops (liquid drops with gas bubbles inside them), and Apfel explored the effect of surfactants on liquid drops. Wang's observations of compound drops might one day aid researchers in the pursuit of a method for encapsulating living cells for treatment of diseases, and Apfel's research of surfactants may contribute to improvements in a variety of industrial processes, including oil recovery and environmental cleanup. Crewmembers had to deploy and manipulate the drops for both experiments, and HI-PAC helped the science teams to guide them in these activities. Apfel reported that the crew was so well-trained and had such sound knowledge of the experiments that they showed "a special intuition" in conducting them. The result of all the interaction and intuition was a benchmark match between Apfel's experiment data and theory.

Wang, however, did not see such a match between his experiment data and theoretical predictions of compound drop behavior. About the discrepancy, Wang exclaimed, "That's real science — it's like real life!" Wang and his team will use the 5 million HI-PAC images of manipulated drops from USML-2 to further their understanding of why the drops behaved differently than expected. Analysis of some of the data gathered during the mission has already given Wang insight into a phenomenon observed during the bifurcation (division into two parts) of drops on USML-1. Looking at USML-2 images, Wang's team began to suspect a coupling mode that they had not detected in USML-1 experiment results. When Wang went back to the USML-1 data with this new suspicion, looking very carefully, he could see the coupling. "Because we didn't think it was there the first time, we didn't look hard enough. With new evidence we could see it," Wang explained. Analysis of the masses of data gathered during the mission continues as does work to identify new biotechnology applications for the knowledge gained through this series of experiments.

"Opening Avenues"

Before the investigators in protein crystal growth and zeolite crystal growth gave presentations at the L+1 review, Joel Kearns, manager of the Microgravity Research Program, introduced Arnauld Nicogossian, acting associate administrator for life and microgravity sciences. Nicogossian prefaced the crystal growers' talks most appropriately by saying that "microgravity research not only allows new discoveries about chemical and physical phenomena in space but also holds the distant promise that one day, based on what we learn in space, we will discover strategic materials that will help life back here on Earth." As the USML-2 crystal growth experiments demonstrated, this vision is more reality than dream.



Crystals of the protein Raf kinase grown on Earth (top) and on USML-2 (bottom) are shown above. The space-grown crystals are an order of magnitude larger. (Photos courtesy of Dr. Jean-Pierre Wery and Eli Lilly and Company)

Although crystals of proteins and viruses grown on USML-1 showed improvement in size and quality of structure when compared to their ground-grown counterparts, those results were surpassed on USML-2. PI Daniel Carter (New Century Pharmaceuticals, Inc.) reported that a large single crystal was grown of the protein raf kinase, which is important in cancer research. Carter said the crystal "opens avenues to the understanding of the protein structure not previously possible." Carter's USML-2 experiment also yielded the highest quality crystal grown to date of the HIV protease combined with an inhibitor. The crystal yielded a 25 percent increase in data and may provide valuable preliminary knowledge for designing new drugs to combat AIDS.

Karen Moore (University of Alabama, Birmingham, UAB) served as co-investigator with PI Lawrence DeLucas (UAB), for the Commercial Protein Growth Experiment. Moore reported that the UAB team found conducting preliminary protein crystal growth experiments in the USML-2 Spacelab Glovebox useful for optimizing conditions for growing proteins in the Vapor Diffusion Apparatus trays also carried on the mission. Although some samples did not grow as successfully as others, in part due to sample deterioration during the long delays in mission launch, the team learned valuable lessons about handling the liquid solutions in the space environment.

The glovebox also played an important

role in Al Sacco's experiment in zeolite crystal growth. Sacco (Worcester Polytechnic Institute), who was a payload specialist onboard USML-2 as well as a PI, learned to manipulate the zeolite solutions in the glovebox for better growth in his experiment. "We grew crystals that were 500-1000 times larger than can be grown commercially on the ground," Sacco reported. Elimination of sedimentation in the microgravity environment accounted for some of the increase in growth, and the improved crystals should yield clues for producing better zeolites on Earth, where they could have such uses as radioactive waste scavengers or as semiconductor material for information storage in computers.

"Which to Pursue?"

The glovebox was also used for small-scale investigations that could later be developed into full-scale experiments. USMP-3 glovebox investigations focused on combustion and demonstrated the unintuitive nature of flames in a microgravity environment. These investigations revealed some never-before observed phenomena. USML-2 glovebox investigations included observing fluid behavior in exotically shaped containers, particle dispersion in clouds, combustion of fiber-supported fuel droplets, and crystallization using hard spheres. Even these small-scale experiments yielded unexpected, unexplained, and very provocative results, all of which will generate new questions for further exploration in the long-term microgravity environment of the International Space Station.

As Project Manager Richard Lauver (Lewis Research Center) observed during the L+1 review, "We see that real science raises as many questions as it answers. The issue of the future will not be to wrestle with conclusions as much as it will be to decide which questions to pursue."

Additional information
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